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A NEW METHOD FOR POWER GENERATION AND DISTRIBUTION IN OUTER SPACE

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A NEW METHOD FOR POWER GENERATION AND DISTRIBUTION IN OUTER SPACE

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INTRODUCTION

The power system is a major component of a space system's size, mass, technical complexity, and hence, cost. To date, space systems include the energy source as an integral part of the mission satellite. Potentially significant benefit could be realized by separating the energy source from the end-use system and transmitting the power via an energy beam (power beaming) (Coomes et al. 1989). This concept parallels the terrestrial central generating station and transmission grid. In this summary, the system components required for power beaming implementation are outlined and applied to a satellite constellation to demonstrate the feasibility of implementing power beaming in the next 20 years.

BEAM-POWER SYSTEM

In a beam-power system, shown in Figure 1, the power system is separate from the end-user. The central power system is coupled with a transmitter to send the power to the remote user. The user replaces its power source with a receiver. The transmitter and receiver selection involves four parameters: 1) the transmission distance, 2) the transmission frequency, 3) the power level transmitted, and 4) the thermal rejection capacity of the various components. The power transmission distance is the key parameter determining the operating frequency because the ratio of power received to power transmitted is only a function of the transmitter and receiver aperture area, the transmission distance, and the operating frequency.

The two frequency options available for energy beaming are radio frequencies (a microwave system) and optical frequencies (a laser system). The microwave technology is available today at 2.45 GHz [Department of Energy (DOE)/National Aeronautics and Space Administration (NASA) 1978a, DOE 1980]. The solid-state laser technology (a 0.833 micron laser transmitter and photovoltaic receiver) is being developed and would be available early in the next century (DOE/NASA 1978b). Both technologies are viable in the projected time frames being considered for transition to power beaming. Therefore, the system selection becomes a tradeoff of the specific mission or energy applications, the transmission distances, and the end-use energy needs.

The Power System

For power beaming to be worthwhile, an appropriate continuous energy source in outer space is needed. At present, two continuous output power sources are

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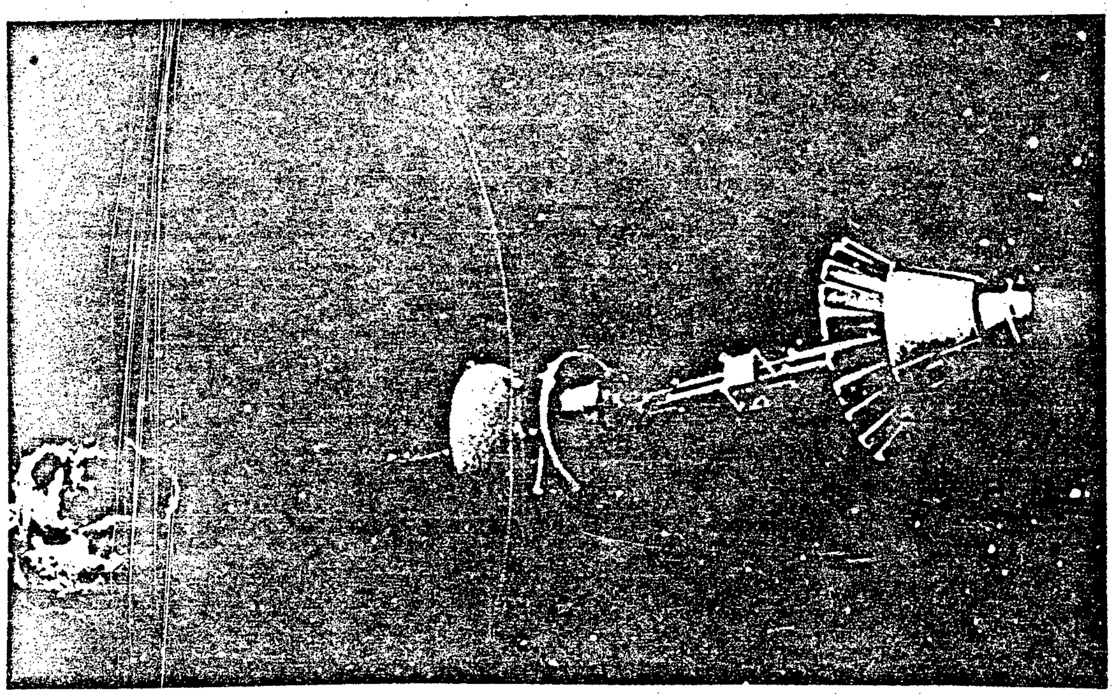

FIGURE 1. Beam-Power System Constellation.

available: solar photovoltaic (PV) systems and radio-isotope thermoelectric generators (RTG). Neither produces enough power to provide a viable prime power source for satellite constellations in a beam-power system.

SP-100 technology power systems currently being developed could provide up to 1 MW of continuous electrical output. The overall system efficiency could be increased from 5% for the current thermoelectric system to 25% or more if a dynamic conversion system were used. The higher conversion efficiency would allow electrical outputs as high as 5 MW employing the same basic reactor designs, which should be available in the late 1990s or early 2000s if SP-100 development continues. The Strategic Defense Initiative (SDI) Multimegawatt Program could develop power systems that could provide tens of megawatts by the year 2010.

PLATFORM ASSESSMENT WITH POWER BEAMING

To compare the benefits of power beaming with the current architecture, an analysis was conducted to replace the on-board power systems with power receptors that track power satellites in a much higher orbit.

For power beaming to be effective, the power system to be replaced must be significantly heavier than the power system used to drive the beam-power satellite. To meet this objective, continuous power requirements of the constellation were considered. The base-line beam-power platform consists of a closed-cycle, continuous-duty nuclear power source powering a solid-state laser. The power source on the user satellite is replaced with an energy

receptor using conventional state-of-the-art solar panel technology with the exception that the solar cells are replaced with single bandgap gallium-arsenic (GaAs) cells tuned to the transmitter output wavelength. Specific masses of these components are varied depending on the technology time frame being assumed (near-term or far-term technologies).

Space Surveillance and Tracking System Analysis

Consider the Space Surveillance Tracking System (SSTS) (General Electric 1987), a constellation of 20 satellites located in high-earth orbit. To determine the effects of transmission distance upon a beamed-power option, systems using from 2 to 10 power satellites were evaluated. Transmitter and receiver apertures were varied to remain within the operating limits for the systems. The maximum allowable power density for a transmitter is 400 W/cm^2; the receiver is limited to an incident energy level of 1.1 W/cm^2. These constraints set the receiver diameter at 1.8 m or greater.

Each satellite requires 8 to 14 kW of continuous power; burst power requirements range from 5 to 15 kW, with the maximum required power of 29 kW (Table 1). Conservatively, an overall beam-power transmission efficiency of 20% was chosen. The entire constellation would require a beam-power satellite system with a minimum power capacity of at least 925 kW. This assumes that stationkeeping power is available during the entire orbit and burst power is available for one-quarter of the orbit.

TABLE 1. SSTS Constellation Details Assumed

Number of SSTS satellites	20
Power required per satellite	
Minimum stationkeeping	8 kW
Maximum stationkeeping	14 kW
Minimum burst mode	5 kW
Maximum burst mode	15 kW
Engagement zone	90 degrees
Power source efficiency	20%
Maximum power required SSTS	13 kW
Minimum power required SSTS	29 kW
SSTS power system mass	
Minimum	800 kg
Maximum	1100 kg

Number of power beaming satellites	2	3	4	6	10
Economy of scale, fraction	1.00	0.99	0.95	0.90	0.80
Power per power-beaming system(a)					
Minimum required, kW	185	187	195	206	231
Maximum required, kW	355	359	374	394	444

(a) Assumes stationkeeping power available for 100% of user orbit and burst mode power for user in engagement zone.

Two technology projections were considered; an SP-100 reactor with a specific mass of 33 kg/kW was chosen for the power system. The far-term projection chosen was an advanced SP-100 reactor with a specific mass of 2 kg/kW. Transmitter technology was also allowed to advance, while receiver technology was held constant. The beamed-power option provides a mass savings for all of the assumptions except the minimum mass assumptions for greater than three beam-power satellites. The far-term assumptions show a significant mass savings in all cases (Table 2).

Break-even points for the assumptions were also calculated. For the near-term transmitter specific mass of 10 kg/kW and a receiver specific mass of 3 kg/kW, the break-even power system mass ranged from 6 to 16 kg/kW. The second analysis using the far-term transmitter specific mass of 1 kg/kW and a receiver specific mass of 3 kg/kW, showed that the break-even power system mass ranged from 17 to 25 kg/kW (Table 3).

With the current approach, SSTS will require approximately 22,000 kg of power systems to be launched for the entire satellite constellation. By utilizing power beaming, the power system mass required is reduced to 7,000 or to 13,000 kg, depending on the specific mass assumptions for the power system.

THE DEBATE -- OPEN-CYCLE VERSUS CLOSED-CYCLE POWER SYSTEMS

To consider all options, power beaming should be compared with on-board, open-cycle systems for providing pulse power requirements. The initial premise was that power beaming could replace on-board, open-cycle pulse power systems with no net penalty to the overall satellite constellation. However, an in-depth analysis showed that the energy penalty associated with beamed power

TABLE 2. SSTS Power System Mass Analysis for State-of-the-Art and Advanced Concept SP-100 Reactor for a Minimum Receiver Diameter of 1.83 m

System Technology Assumptions											
Near-Term Technology Specific Mass						Far-Term Technology Specific Mass					
SP-100 power source	33 kg/kW					SP-100 power source	2 kg/kW				
Laser transmitter	10 kg/kW					Laser transmitter	1 kg/kW				
Photovoltaic receiver	3 kg/m2					Photovoltaic receiver	3 kg/m2				
Constellation Mass Savings Using Power Beaming											
Mass Savings With Near-Term Technology, kg						Mass Savings With Far-Term Technology, kg					
SSTS Power System	Number of Beam-Power Satellites					SSTS Power System	Number of Beam-Power Satellites				
	2	3	4	6	10		2	3	4	6	
Minimum	686	532	-117	-1010	-3130	Minimum	13380	13369	13324	13326	
Maximum	6686	6532	5883	4990	2870	Maximum	19380	19369	19324	19326	

TABLE 3. Power System Break-Even Point for State-of-the-Art and Advanced Concept Transmitter at a Minimum Receiver Diameter of 1.83 m

System Technology Assumptions										
Near-Term Technology Specific Mass						Far-Term Technology Specific Mass				
SP-100 power source TBD kg/kW Laser transmitter 10 kg/kW Photovoltaic receiver 3 kg/m^2						SP-100 power source TBD kg/kW Laser transmitter 1 kg/kW Photovoltaic receiver 3 kg/m^2				
Beam-Power Satellite Power Source Specific Mass To Break-Even										
Break-Even Point With Near-Term Technology, kg/kW						Break-Even Point With Far-Term Technology, kg/kW				
SSTS Power System	Number of Beam-Power Satellites					SSTS Power System	Number of Beam-Power Satellites			
	2	3	4	6	10		2	3	4	6
Maximum	52	51	49	46	40	Maximum	61	60	58	55
Minimum	35	34	33	30	26	Minimum	44	43	42	39

ranged from 1.4 to 4 times that of the on-board, open-cycle system. If open-cycle systems are not acceptable, power beaming has the potential to perform the same mission with no net penalty. With current technologies, an power-beaming system would require four times the mass to provide the pulse power currently expected from open-cycle systems (chemical or nuclear). With technology advances in 15 to 20 years, power beaming would still require about one-and-one-half times the mass of an open-cycle system. Should open-cycle power sources be deemed an unacceptable means of providing pulse power requirements, thereby requiring the closed-cycle pulse power option, power beaming would then be a viable alternative requiring the same amount of mass to meet the pulse power requirements.

CONCLUSIONS

Power beaming can significantly benefit future space missions. Beam-power transmission is technically feasible. The systems, transmitters, receivers, and power sources are expected to be available in a time frame compatible with proposed deployment schedules. Power beaming is most attractive and can provide significant benefit for stationkeeping and alert mode power. With near-term technologies, power beaming can provide the stationkeeping and alert mode power for only one-half of the on orbit mass of the currently proposed power system.

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